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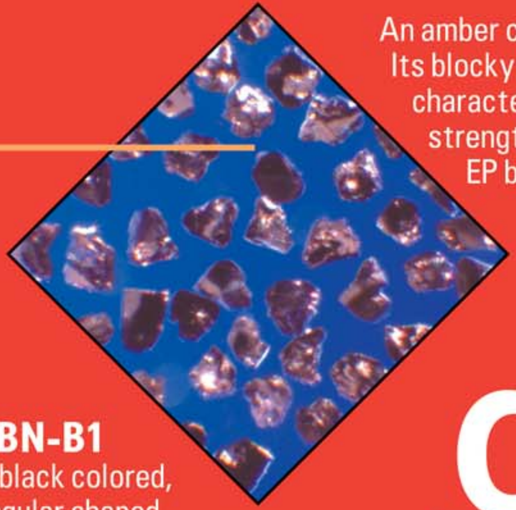

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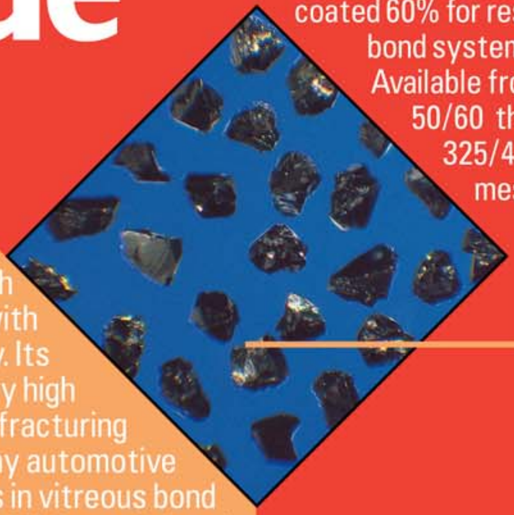

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COVER PHOTO

The Aerospace industry will be looking for faster implementation of superabrasives cutting and grinding tools for aircraft components made of superalloys and aluminum. Boeing is building C-32As to replace the Air Force's aging fleet of VC-137s. The airplanes will carry cabinet members of the executive branch, the U.S. Vice President and members of the U.S. Congress when they travel on government business. Photo courtesy of Boeing Company.

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FINER POINTS is the only publication devoted exclusively to the understanding, selection and application of diamond, cubic boron nitride and related materials. It is edited for recipients who are involved in some way with these "superabrasives", either as providers of the materials, producers of products containing the materials or users of these products (e.g., grinding wheels, dressing tools, drill bits, saw blades, sawing wires, cutting tools, polishing compounds, CVD film products, etc.).

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A Finer Point of View…

INTERTECH 2006
April 24 –26 2006
Atlanta Georgia USA

This past October, I enjoyed attending the first Diamond at Work Conference in Barcelona, *my third diamond-oriented technical conference of 2005*. Opening the conference, Christian Hultner of Element 6 *pleaded* with us to invest in innovation and showed how companies from other industries that had embraced innovation enjoyed higher ROI. Tanya Fratto of Diamond Innovations continued the theme to open the second day, although with more balance, noting the innovations in our trade from the past decade and exhorting us to continue.

Why the new emphasis on innovation? It's clear from the number of technical meetings that, 15 years after the CVD diamond boom started, there is still ample funding for basic research into this process, the many new forms of carbon it produces, and how they might be applied to solve today's problems. Fifteen years seems a long time, however, in today's product life cycles. The successful commercial products from this technology are few and we haven't seen a blockbuster, yet.

Innovation continues unabated in the more traditional industrial diamond areas with new coatings and bonds, novel applications for grit, micron and now nano materials and modified processes to allow the use of superabrasives where they didn't fit before. These changes are needed to make room for the new low-cost suppliers our expanding global economy is creating. But can we grow demand and value as quickly as supply is growing?

PRESIDENT
Joseph Tabeling

INTERTECH 2006 is our third global conference this decade dedicated to bringing together manufacturers and users of superabrasive products. The needs of a user combine with the technology of a producer to create novel solutions. Add inspiration provided by leading application experts from around the world and INTERTECH is the perfect forum for all manner of innovation.

Rapid innovation depends upon exploiting each other's strengths through partnership and these partnerships start at meetings like INTERTECH.

INTERTECH 2006 continues the wave of end user, supplier and researcher collaboration that is paramount for our industry to achieve the promise of forecasted growth. Join your peers in Atlanta this April to learn what's new in the world of superabrasives and get energized for developing and applying these new innovations…

Sincerely,

JW Tabeling

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Photo courtesy of Boeing Company.

HIGH SPEED FINISH MILLING of Ti6Al4V with PCD

By: D. Barnett-Ritcey
McMaster Manufacturing Research Institute, McMaster University, Hamilton, Ontario Canada

In the aerospace industry superalloy materials are used for aircraft components. These super light and difficult to machine alloys create numerous problems for cutting tools that are overcome by the use of polycrystalline diamond (PCD). There are many key issues and critical conditions for failure under mechanical and thermal loading indicative of finish milling operations at high speeds of 1500-4500sfm. We will explore the effect of cutting conditions (speed, radial immersion, chip load, cooling method) and tool material properties (TRS, thermal conductivity, etc). Various PCD grades were tested to determine the most appropriate attributes. There is also a case for the economic acceptance of finish machining with PCD versus carbide (WC) tools.

MILLING TITANIUM WITH EXTENDED CUTTING TOOL LIFE

Titanium is known as a difficult-to-machine material, especially at higher speeds owing primarily to its low thermal conductivity. The aerospace industry produces both airframe and engine components (*photos 1& 2*) from titanium alloy, in which machining time becomes a substantial factor in the final product cost.

This investigation shows that it is possible to finish mill Ti6Al4V at 457-1372 m/min (1500-4500sfm), and yield reasonable tool life (12-215m). The effect of each key cutting parameter (*V, a_e, h_x see nomenclature chart 1*) value and coolant condition has a large effect on the attainable tool life.

HIGH-SPEED MILLING OF TI6AL4V USING PCD

Few papers concerning the high speed milling (HSM) of titanium alloy using PCD exist. For fine peripheral finishing cuts, speeds of 110 m/min, 500 m/min and 610 m/min have been reported. We will first determine the useful range of PCD, and then investigate various PCD grades under five cutting conditions to determine the most appropriate attributes to optimize.

Tool life (*TL*) in milling is analogous to high cycle fatigue, whereby the chip load (h_x) represents the mechanical load; the cutting speed (V) represents the magnitude of the thermal load; and radial immersion (a_e) represents the duration of exposure to the thermal load. Increased cutting speed increases the rate of heat generated, hence generating higher temperatures. Increased immersion increases the exposure of the tool to high temperatures. Increased chip thickness increases the mechanical shock load on the tool. The coolant condition influences thermal shock, via the heat transfer coefficient (*h*). Water provides a larger h than air, while increased pressure increases the *h*-value for both.

TOOL FACE TEMPERATURE

Principally, the control of heat is essential to successfully machine titanium alloys at high speed. The tool face temperature achieved in turning represents an upper bound of temperatures expected in milling. As the cutting speed is increased, the temperature increases to until the melting point of Ti6Al4V (1650°C) is reached (*figure 1*). The data points plotted in *figure 1* were taken from tool wear literature and fitted with an error function (instead of the usual power function) to capture this behaviour. The upper and lower solid lines denote a temperatures for a chip thickness of 0.127mm (0.005") and 0.022mm (0.00087") respectively. The dashed lines between denote temperatures at 0.025, 0.038, 0.076 and 0.114mm (0.001, 0.0015, 0.003, and 0.0045") chip thickness.

Both PCD (h_x=0.025mm) and WC (h_x=0.114mm) exceed their continuous use temperature (700~900°C) at low cutting speeds (152 and 84m/min respectively). Moving to 457-1372 m/min (1500-4500sfm) with PCD would produce tool face temperatures of 1125-1505°C.

TOOL LIFE RELATIVE TO TEMPERATURE

The influence of temperature (a function of *V*) and duration of exposure to this temperature (a function of a_e, *D*, and *V*) on tool life has previously been summarized for WC tooling on Ti6Al4V. Briefly, for a finishing operation that achieves a residence time of less than the critical time, a large increase in tool life will result. For higher cutting speeds the critical time will be shorter, hence the feasible a_e range will be smaller. For this investigation, the tool life criterion used to define tool life, are described in *table 1*.

EXPERIMENTS ON TITANIUM WITH PCD

Testing of plate and forged Ti6Al4V (300 HB) was performed at high speed (*table 2a*) using seven PCD grades (*table 3*) under various coolant conditions (*table 2b*). All inserts were of the XPHW-160408 type (a flat insert with 0.80mm (0.031") nose radius). The cutting edge was sharply ground having an edge radius of less than 5um (<0.0002") set at axial and radial rake angles of –11.5° and 2° respectively. Unless otherwise noted, all tests utilize only one insert and refer to an axial immersion value of 2.54mm (0.100").

MATERIAL PROPERTIES

To identify the critical conditions for failure under mechanical and thermal loading indicative high-speed machining of Ti6Al4V, the material properties of the tool, material, and their relevance need to be discussed.

Photo 1 – Aircraft Production (courtesy of Boeing Co.)

Photo 2 - Assembly of Boeing Engine (courtesy of Boeing Co.)

Nomenclature Chart 1

V	*Cutting speed (m/min)*
h_x	*Chip load or maximum chip thickness (mm)*
a_e	*Radial immersion (mm)*
a_p	*Axial immersion (mm)*
D	*Diameter of endmill (mm)*
TL	*Tool life (m)*
TRS	*Transverse Rupture Stress (MPa)*
λ	*Thermal conductivity (W/m.K)*
γ	*Thermal Diffusivity (m2s)*
α	*Coefficient of thermal expansion (10-6/K)*
*R*γ	*Thermal Shock Resistance Factor*
h	*Heat transfer coefficient (W/m2.K)*
TSC	*Through the spindle coolant*
TSA	*Through the spindle air*

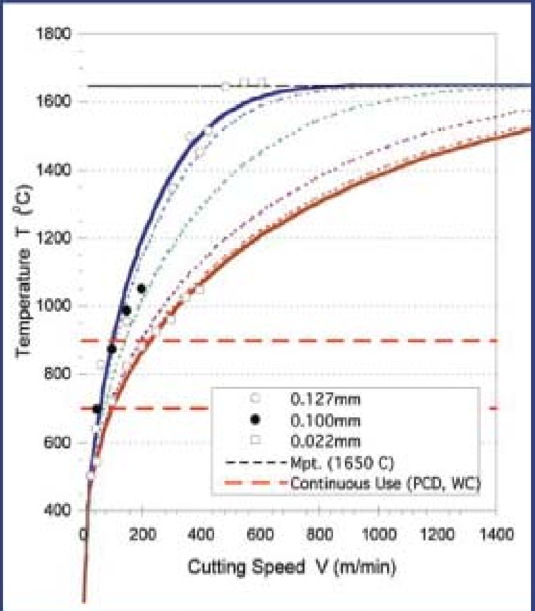

Figure 1: Average temperature at the tool/chip interface when turning Ti6Al4V

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TOOL MATERIAL PROPERTIES

The properties for seven PCD (*photo 3*) and one WC tooling grade are summarized in *table 3*. Observable trends are as follows:

- Smaller grain size requires more binder to sinter {*lower maximum use temperature*}.
- Declining grain size imparts increased Griffith flaw behaviour or Transverse Rupture Stress (TRS) but reduces the toughness of the cutting edge {*increased resistance to crack initiation, but reduced resistance to crack propagation*}
- Thermal conductivity increases with E, relative to amount of crosslinking between diamond grains {*reduced thermal gradients*}.
- Density, specific heat capacity and thermal expansion may be considered constant between different grades of PCD.
- In general, when comparing PCD grades to WC, WC exhibits a higher TRS, but lower thermal conductivity and hardness.

WORKPIECE MATERIAL PROPERTIES

A low thermal conductivity (7 W/m.K) coupled with a high melting point (1650°C) enable high cutting temperatures at low cutting speeds in Ti6Al4V. In general, cutting forces were observed to decline with cutting speed (*figure 2*) and *forged* Ti6Al4V is more abrasive than *plate*. Additionally in the forged material, an abrasive near-surface layer (skin) exists that imparts higher cutting forces and reduced tool life (*figure 2*).

PROPERTY RELEVANCE TO MACHINING

In order to avoid rake face chipping from mechanical overload, the TRS of the tool material must be greater than the applied load. The TRS of brittle materials is not deterministic in nature. The spread of the TRS value is defined by the Weibull modulus (probability of exceeding TRS) of the material. Typical ranges for PCD and WC would be 10-15, and 30-35 respectively. Since a small values signify a narrower distribution, PCD tools may fracture significantly below their quoted TRS values.

To avoid rake face chipping due to thermal shock, the appropriate parameter must be maximized. Depending on heat flow conditions the following thermal shock factors are relevant:

$R = TRS\,(1-\nu) / E\alpha$ *Bulk Transient*
$R\gamma = \gamma\,(R)$ *Local Transient*

For avoiding fracture initiation by thermal shock, the favourable material characteristics include high values of TRS and γ (or λ), coupled with low values of E and α. Since only the tip of the insert is heated, the gradient at the heated/cooled surface may be the region of primary interest. Hence, *Rγ* should be the factor more relevant to machining. Therefore, WC has the best bulk thermal shock resistance while PCD always has the best local thermal shock resistance (*table 3*). If the above are satisfied, optimizing flank wear inside of these bounds becomes the only concern. Practically, both mechanisms may act independently. The largest component of mechanical load will act as the insert enters the cut while the thermal shock will act as the insert leaves the cut and enters the coolant stream.

Table 3: Material properties for seven PCD and one WC tooling grade.

Property			E30 (1)	CTM302 (2)	CTB002 (2)	CTB010 (2)	CTB025 (2)	1600 (3)	1300 (3)	H10F (4)
Average Grain Size		(um)	18	2-30	2	10	25	4	5	< 1
Binder Composition (%Co)			N/A	10%	20%	12%	12%	10%	8%	10%
Balance			PCD	PCD	PCD	PCD	PCD	PCD	PCD	WC
Young's Modulous	*E*	(GPa)	1019*	1049	749	982	1056	850	950	580
Poisson's Ratio	ν		0.093*	0.0713	0.0700	0.1020	0.0845	0.08*	0.08*	0.22
Fracture Toughness	K_{IC}	(MPa.m$^{1/2}$)	8.64*	8.4	6.86	8.39	8.89	N/A	N/A	N/A
Transverse Rupture Stress	*TRS*	(MPa)	1317*	1152	1550	1356	1278	1700	1400	3000
Density	ρ	(kg.m3)	4046*	3982	4240	4104	3988	4100	4000	14500
Thermal Conductivity	λ	(W/m.K)	650*	650*	500*	540	760	500	525	85
Specific heat Capacity	C_p	(J/kg.K)	500*	500*	500*	500*	500*	500*	500*	400*
Thermal Diffusivity	γ	(10-6m2s)	321*	326	236	263	381	244	263	15
Thermal Expansion	α	(10-6/K)	4.4*	4*	4*	4.2	4.6	4.1*	4.1*	5.5
Thermal Shock Factor - I	*R*		266,000	255,000	481,000	295,000	241,000	449,000	331,000	734,000
Thermal Shock Factor - II	*Rγ*		86	83	113	78	92	109	87	11

Note: (*) Denotes an estimated value, (N/A) indicates information not available. Information from Suppliers {(1) US Synthetic, (2) Element Six, (3) Diamond Innovations and (4) Sandvik} was obtained through private communication or product literature.

Table 1: Tool life criterion

CONDITION	LIMIT	DESCRIPTION
VB (1)	*600 um*	*Max. flank wear at the tool tip.*
VB (2)	*300 um*	*Avg. flank wear in centre portion*
VB (3)	*600 um*	*Max. flank wear at depth of cut.*
VB	-	$\frac{1}{4}[VB(1) + 2VB(2) + VB(3)]$
CHP	*Loss of defined cutting edge, chipping.*	
CAT	*Total loss of edge, catastrophic failure.*	

Table 2a: Range of Cutting Conditions

CONDITION	RANGE
V	*229-1372 m/min (750-4500 sfm)*
a_e	*0.25-2.03 mm (0.010-0.080")*
h_x	*0.013-0.076 mm (0.0005-0.003")*
a_p	*2.54 mm (0.100")*
D	*19.05 mm (0.750")*

Table 2b: Coolant Conditions

DRY	*No coolant application (no forced air)*
A#	*Externally applied pressurized air: 0.069-0.69MPa (10-100psi).*
TSA#	*Pressurized through-spindle air. 0.069-0.69MPa (10-100psi)*
FLO	*Externally applied water-based coolant.*
OD	*low pressure*
TSC#	*Pressurized through-spindle water based coolant. 2.1-6.9MPa (300-1000psi)*

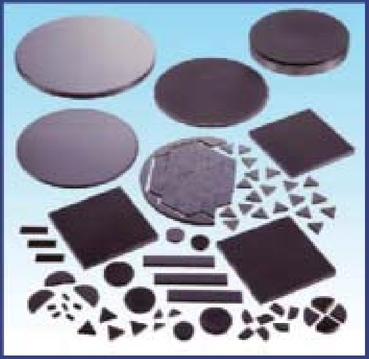

Photo 3 PCD Tool Blanks (courtesy of Element 6)

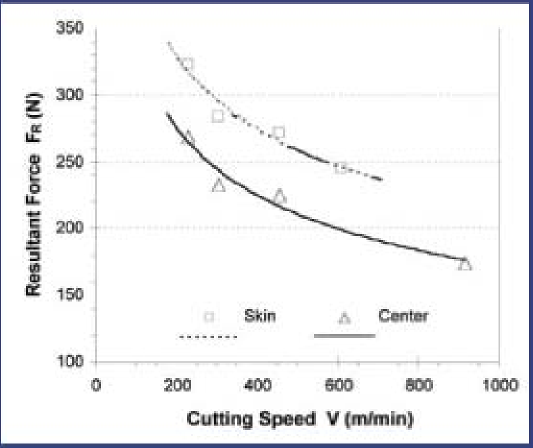

Figure 2: Effect of cutting speed on cutting force. (forged, h_x=0.025mm, a_e=0.25mm, A50)

OPTIMIZING THE MOST APPROPRIATE MACHINING ATTRIBUTES

This article will first present the experimental work done to determine the application range of PCD, then chronicle the investigation of various PCD grades under five cutting conditions and determine the most appropriate attributes to optimize.

APPLICATION RANGE OF PCD

Initial trials, chosen to test PCD at carbide cutting conditions (V=190m/min, h_x=0.076mm, a_e=0.51mm) under low-pressure air, resulted in low tool life (1.5m) exhibiting rapid flank wear and rake face chipping. Increasing the cooling power to TSC300 resulted in slightly longer tool life (2.8m) with significantly reduced flank wear but severe rake face chipping. By reducing the mechanical load (h_x to 0.057mm, and V to 229m/min) at an a_e of 0.25mm, tool life increased to 7.1m. Further decreases in h_x coupled with increases in V failed to increase the tool life past this point. Increasing the cooling power to TSC1000 (from V=457m/min, h_x=0.025mm, TSC300) decreased the tool life from 5.3m to 3.0m due to rake face chipping. In order to avoid rake face chipping but retarded flank wear progression, high-pressure air was used as a 'soft-cool'. Under A50, 91m of tool life were achieved without rake face chipping.

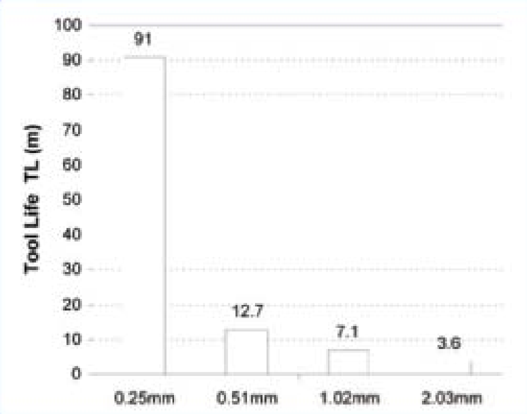

Figure 3: Effect radial immersion on tool life. (plate, V=457m/min, h_x=0.025mm, TSA50, E30)

HEAT GENERATION RATE & RESIDENCE TIME

Increasing V increases the heat generation rate, while increasing ae increases the residence time in the cut. Combined they determine the amount of heat entering the tool per revolution. Upon entering the cut, the immediate surface of the tool will reach temperatures of 1125-1505°C. At depths below the surface there will be a 'time-lag' effect, exposing the tool material at this point to lower maximum temperatures. Limiting the amount of material that exceeds a known continuous use temperature (700~900°C for PCD) will significantly prolong tool life. Depending on the cutting conditions, the effect of reducing a_e on tool life will be slight at high immersions (long residence time), but may be significant at low immersion (short residence time - *figure 3*).

At low speeds the heat generation rate may be treated as a constant but reduces as the temperature approaches the melting point of the workpiece material (*figure 1*).

COOLANT CONDITIONS & THERMAL SHOCK

Increasing air pressure can significantly increase tool life over dry while avoiding thermal shock to the insert. The heat transfer coefficient for air may reach 2,000 W/m²K, and 25,000 W/m²K for water (*table 4*) depending on the application and tool temperature. All else being equal, the heat transfer coefficient determines the thermal stress gradient in the insert, which may lead to thermal shock (a high coefficient means more shock). Cooling may be necessary for survival for high-speed milling, but it is preferable to employ a 'soft-cool' with pressurized air than a 'hard-cool' with water.

The practical effect of h on tool life is to determine the wear mode (*figures 4 & 5*). At low values of h wear is due to progressive

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flank wear (I), while at excessive values of h wear is due to rake face chipping (II). In mode I an increase in *h* will act to retard flank wear progression and increase tool life. In mode II, an increase of *h* will provide greater thermal stress, causing larger rake face chips to form earlier. At intermediate values of *h* micro-chipping assisted flank wear is observed (I + II). This mixed-mode wear mechanism is simply progressive flank wear augmented with periodic localized edge chipping.

The onset of mode I + II arises when the stress due to thermal shock exceeds the TRS of the tool material. Below a threshold value of *h* the probability of nucleating a chip will be 0% (mode I). For the same cutting condition there exists a value of *h* that will ensure a chip forms (100% probability, mode II). Between these, and centred about an *h* value corresponding to the TRS of the tool material, the tool life for mode I + II will decline from mode I toward mode II (*figure 5*). The breadth of mode I + II would be determined by the Weibull modulus of the tool material.

MECHANICAL LOAD EVALUATION

The force on the tool is determined by chip load (h_x), cutting speed (*V*) and the average flank wear (VB). With increasing h_x, the cutting force increases monotonically from a basic value associated with the magnitude of edge radius. Since hx is typically low (0.019-0.038mm (0.00075-0.0015")) for PCD, the edge radius may play a significant role in determining the magnitude of the ploughing forces present. Below an h_x of 0.019mm the tool life was observed to decline as a result of increased ploughing. Above h_x values of 0.025-0.032mm (0.001-0.00125") tool life was observed to drop significantly (*figure 6*) accompanied by extensive rake face chipping.

That the cutting force increases with a decrease in *V* has been shown in *figure 2*. Therefore, with declining speed, the force on the tool may approach the TRS of the tool material and cause chipping of the cutting edge. This would act to reduce tool life due to a change in failure mechanism.

Typically, cutting speeds below 305m/min (1000sfm) exhibit significantly reduced tool life or catastrophic failure (*figure 7*). Over the first 50um, flank wear increases the cutting force rapidly from an initial value F_0 before assuming a reduced slope at F^*_{50} (*VB*>50um) (*figure 8*). The difference between the intercept of the reduced slope (F^*_0) and F_0 (ΔF_0) represents the combined parasitic force due to chip welding, and edge blunting of the tool. The portion of this parasitic force due solely to wear (denoted by $\Delta F^*_{VB} = F^*_{VB} - F^*_0$) may extend to 1-2 times F_0; the total parasitic force will ultimately reach 3-5 times F_0.

The significant fluctuation present in the force values arises from the following observations. At high VB in all PCD tooling that exhibits mode I progressive flank wear, a 'spalling' fracture occurs solely on the flank face. The spall leaves a fracture surface in the PCD that does not contact the workpiece material, effectively reducing the wear scar temporarily. The fracture surface is never deep nor has it ever extended to the cutting edge. It serves to periodically decrease the actual wear area, thus decreasing the ΔF^* at high *VB*. Under mode I + II and mode II the spalling effect exists in conjunction with edge and rake face chipping. In this case, chipping also alters ΔF_0 by changing the edge geometry. This may temporarily provide lower forces (due to a sharply fracture edge) but ultimately increases the force due to an increasingly negative rake.

PERFORMANCE OF PCD GRADES

Previously, the majority of the testing has been done using E30 (on plate) and CTB010 (on forged). In this section, seven grades of PCD from 3 manufacturers were tested under five cutting conditions to explore the impact of increased speed, increased chip load, increased immersion, and reduced heat transfer coefficient from a base line test (*table 5*). The baseline test conditions (on plate Ti6Al4V) were chosen to ensure measurable tool life in all tested grades. The following results should be prefaced by the knowledge that other grades (*Photo 4*) from each manufacturer exist. The goal is not to identify the best manufacturer, but to determine what properties to optimize in a PCD tool material. Currently, there are no PCD grades designed specifically for HSM of Ti6Al4V.

The tool life values under the baseline cutting condition are present for each grade in *figures 12-15*.

It is apparent that increased TRS (*figure 9*) and $R\gamma$ (*figure 10*) improve tool life. Since reduced grain size typically increases TRS, it is also seen to increase tool life (*figure 11*). While the trend stays consistent, there appears to be a shift in the values from one manufacturer (•, *figure 9-11*). This is most likely a difference in binder formulation. With respect to thermal shock, CTB010 (□, *figure10*) deviates from the trend due to a low γ value. This may yield good results under high mechanical load conditions, but will render CTB010 more susceptible to thermal shock than CTB002.

Table 4: Approximate range of heat transfer coefficient values

DESCRIPTION	HEAT TRANSFER COEFFICIENT h (W/m²k)	APPLICATION
Low-speed Air	*10-100*	*DRY*
High-speed Air	*100-2,000*	*A# & TSA#*
Low-speed Water	*2,000-5,000*	*FLOOD*
High-speed Water	*5,000-25,000*	*TSC#*

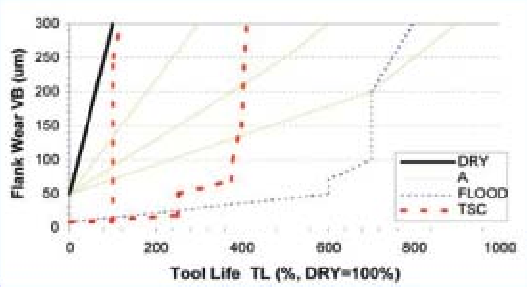

Figure 4: Effect of the heat transfer coefficient on tool wear progression (schematic).

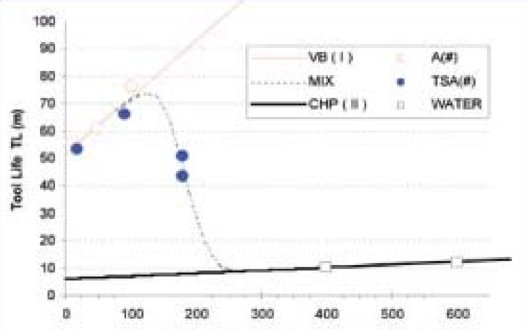

Figure 5: Effect of the heat transfer coefficient on tool life (forged, V=305m/min, h_x=0.025mm, a_r=0.25mm, CTB010)

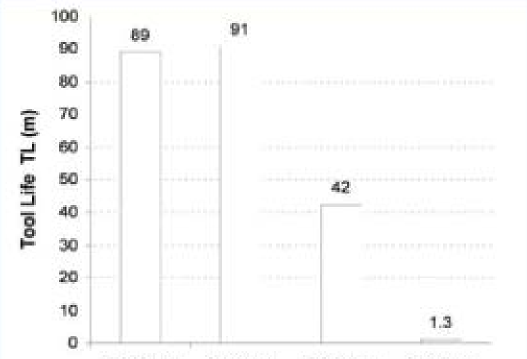

Figure 6: Effect of chip load (hx) on tool life. (plate, V=457m/min, a_r=0.25mm, A50, E30)

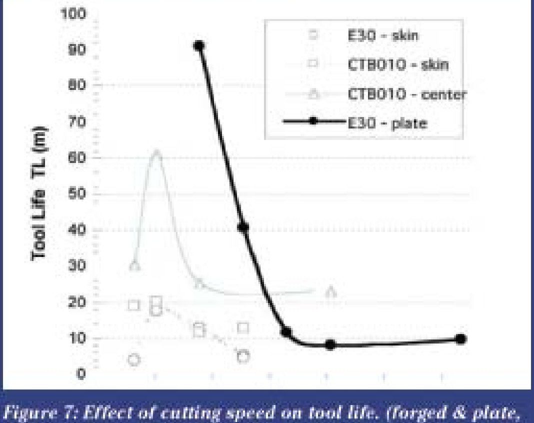

Figure 7: Effect of cutting speed on tool life. (forged & plate, h_x=0.025mm, a_r=0.25mm, A50)

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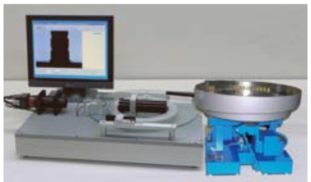

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Photo 4 – various diamond mesh sizes/grades determine PCD performance (Courtesy of Diamond Innovations)

A significant tool life increase of (195% over E30) was achieved by CTB002 due to grade optimization at V=457m/min, h_x=0.025mm, a_e=0.25mm, TSA50 (*figures 12-15*).

EFFECT OF CUTTING SPEED ON PERFORMANCE

Under increased cutting speed, all tool grades yield a tool life value in the 26-53m range (*figure 12*). Data from E30, 1600 and 1300 grades indicate that 762m/min (2500sfm) represents a local tool life maximum. At higher speeds 1600 & 1300 were observed to outperform E30, while the opposite was observed a lower speeds. A significant drop in tool life to 20-54% of the baseline value was observed in most grades, but two grades (1600, 1300) actually improved their tool life from the baseline. CTB002 experienced the sharpest decline owing to its high binder content. Improved tool life (for 1600 & 1300) is plausible due to a lower of the mechanical forces (at increased V) shifting the wear mode from I + II to I. Only a slight increase in tool life (26% over E30) was achieved by CTB010 due to grade optimization at 762 m/min.

EFFECT OF CHIP LOAD ON TOOL LIFE

A significant drop in tool life to 7-32% of the baseline was observed for all grades (*figure 13*). An increase in mechanical load (increasing h_x) would push the wear mode from I to II, dramatically diminishing tool life. A significant increase in tool life (195% over E30) was achieved by CTB002 due to grade optimization at 0.038mm.

RADIAL IMMERSION EFFECT ON TOOL LIFE

A significant drop in tool life to 15-40% of the baseline was observed in most grades, with 1600 only losing 10% of its baseline tool life (*figure 14*). Doubling the a_e increased the time in the cut form 0.289ms to 0.410ms allowing 41% more heat into the insert. A significant increase in tool life (150% over E30) was achieved by CTB002 due to grade optimization at 0.25mm.

EFFECT OF COOLANT CONDITION OF TOOL LIFE

The effect of decreasing air pressure on tool life ranged from a 83% drop (E30) to a 32% increase (1600) in tool life (*figure15*). E30 likely has the least abrasion resistance, while 1600 likely shifted its wear mode from I + II towards I. Of the grades yielding the highest tool life values (CTB002, CTB010 and CTB025), a slight reduction to 67-77% of the baseline was typically observed (*figure 15*). An exceptional increase in tool life (1210% over E30) was achieved by CTB002 due to grade optimization at TSA10.

KEY OBSERVATIONS OF TOOL PERFORMANCE

High *TRS* and Rγ materials performed the best. The 1600 grade outperformed 1300 in nearly all test conditions, while (of the remaining grades), CTB002 was the best over all conditions except at high speed. That 1300 and CTB010 performed better at high speed, is due to a reduced binder content imparting slightly higher heat resistance over a narrow *V* range. It has been noted that there is an upper limit on radial immersion, both upper and lower bounds on chip load and cooling power, and a lower threshold for cutting speed with a local maximum occurring near 762m/min (2500sfm).

This 'dromedary' type of *TL* versus *V* behaviour has been previously been observed in the hard turning of 100Cr6 with PCBN. Three possible mechanisms may contribute to the formation of this effect (seen in *figure 16*):

- Chatter at a frequency corresponding to 610m/min (2000sfm), leading to a local minimum tool life due to excessive cutting force.

Table 5: Cutting conditions used to explore effectiveness of PCD grades.

Test	V	h_x	a_e	h
Baseline	457m/min (1500sfm)	25um (0.001")	254um (0.010")	TSA50
V (+)	762m/min (2500sfm)	25um (0.001")	254um (0.010")	TSA50
h_x (+)	457m/min (1500sfm)	38um (0.0015")	254um (0.010")	TSA50
a_e (+)	457m/min (1500sfm)	25um (0.001")	508um (0.010")	TSA50
h (-)	457m/min (1500sfm)	25um (0.001")	250um (0.010")	TSA10

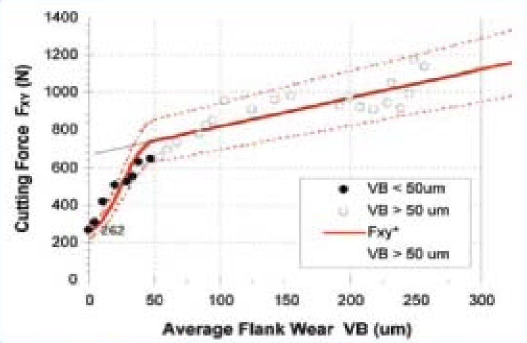

Figure 8: Effect of flank wear on cutting force. (plate, V=457m/min, h_x=0.025mm, a_e=0.025mm, TSA50, CTB002)

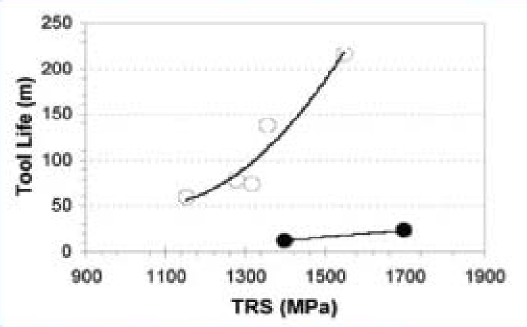

Figure 9: Effect of TRS on tool life (Baseline)

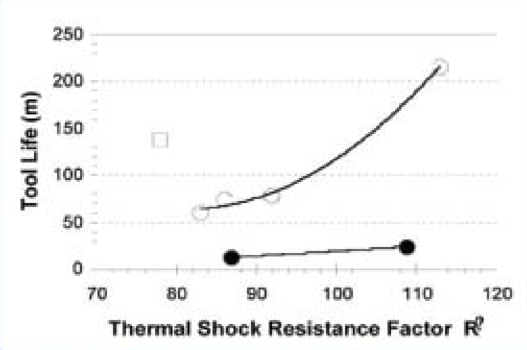

Figure 10: Effect of R γ on tool life (Baseline)

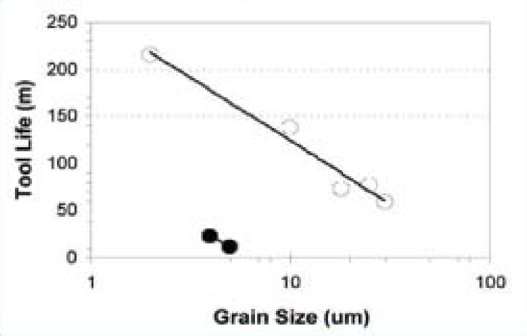

Figure 11: Effect of grain size on tool life (Baseline)

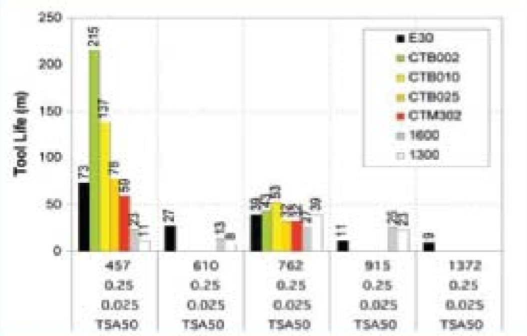

Figure 12: Effect cutting speed on tool life (h_x=0.025mm, a_e=0.25mm, TSA50)

- Reduced cutting force on the shear plane due to a phase transformation in Ti6Al4V at 995°C, which owers the force on the tool.
- Increased toughness of the PCD tool due to thermal softening of the cobalt binder phase. This will act to diminish the effect of chipping under wear mode I + II.

Of these, the last two options seem more plausible. No evidence of chatter or locally increased cutting force is present at 610-686m/min. While forces at 762m/min are expected to be less than those at lower speeds and continue to diminish at higher speeds, evidence of locally decreased forces (70% of the that expected) at 762m/min exists for some cutting conditions. The extent that an insert may toughen with temperature will depend on the grades microstructure. If the wear mode is of type I, no chipping will result and there should be no appearance of a local maximum tool live value at 762m/min. For insert grades more prone to mode I + II wear, the magnitude of a local maximum should be large.

A CASE FOR PCD TOOLING VS. CARBIDE

Tool life values for PCD (CTB002, CTB010) and that of a coated carbide tool are presented in table 6. Feed rates (relative to WC at *V*=229m/min and h_x=0.076mm) for PCD are initially less than WC but yield much longer tool life. Trading tool life for feed rate, by increasing h_x, yields feed rate and tool life values similar to those for carbide. Increasing *V* is preferred since it yields greater rewards for both.

The real niches for PCD tooling exists were there is a limit on the chip load (h_x), especially high-speed finish machining of thin wall structures. Carbide tooling experiences significant edge rounding at speeds above 229m/min (750sfm), thereby, restricting its practical use to h_x values of 0.038mm (0.0015") or greater. Reducing the h_x for carbide to this minimum yields a low feed rate coupled with tool life values about half that of PCD. To increase the tool life the only recourse is to reduce cutting speed slowing the process further. At 1372m/min, PCD is capable of yielding 11m (forged, CTB010, h_x=0.019mm, A50) and 9m (plate, E30, h_x=0.025mm, TSA50) of tool life at a relative feed rate of 3.375 and 4.5 respectively.

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DETERMINING TOOL PERFORMANCE IN HIGH-SPEED FINISHING OF TI6AL4V WITH PCD

Through a large body of experimental evidence, this investigation has shown the following issues to be of importance when determining the tool performance in high-speed finishing of Ti6Al4V with PCD:

- Maximizing both TRS and Rγ values will produce a robust tool capable of high tool life values. Increasing the TRS usually requires a reduced grain size PCD grade.
- The chip load (h_x) must be kept between 0.019mm (0.00075") and 0.032mm (0.00125") to avoid mechanical overload.
- Cutting speeds (*V*) must be kept above 305m/min (1000sfm) to avoid mechanical overload but will yield reasonable tool life to 1372m/min (4500sfm). A local tool life maximum exists at 762m/min (2500sfm).
- Radial immersion (a_e) values must be kept below 0.050mm (0.020") to achieve reasonable tool life.
- Using pressurized air as coolant is essential to ensure the survival of the cutting edge, but an optimum 'soft cool' is required to yield long tool life. An increase in TL with increasing h indicates an under cooled condition, while a decrease in TL with increasing h indicates an over cooled condition. Care must be taken to ensure that mode I wear progression is maintained.

Ultimately when high speed finish milling Ti6Al4v, it is possible to achieve 215m of tool life at 457m/min or 11m at 1372m/min using PCD. ■

Table 6: Tool life and relative feed rate of PCD and WC tooling (plate, ae=0.25mm, TSA50)

	V (m/min)	hx (mm)	Relative Feed Rate	TL (m)
WC	229	0.038	0.50	~74
WC	229	0.076	1.00	20-29
PCD	457	0.025	0.66	137-215
PCD	762	0.025	1.11	43-53
PCD	457	0.038	1.00	14-29
PCD	1372	0.019	3.38	11
PCD	1372	0.025	4.50	9

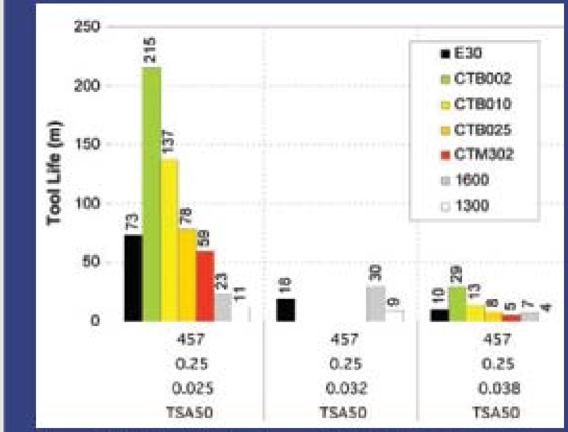

Figure 13: Effect chip load on tool life (V=457m/min, a_e=0.25mm, TSA50)

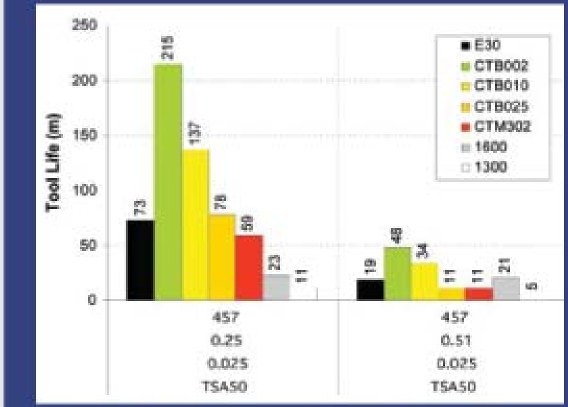

Figure 14: Effect radial immersion on tool life (V=457m/min, hx=0.025mm, TSA50)

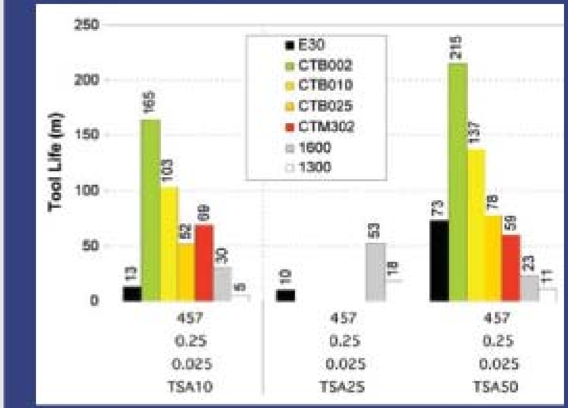

Figure 15: Effect coolant condition on tool life (V=457m/min, h_x=0.025mm, a_e=0.25mm)

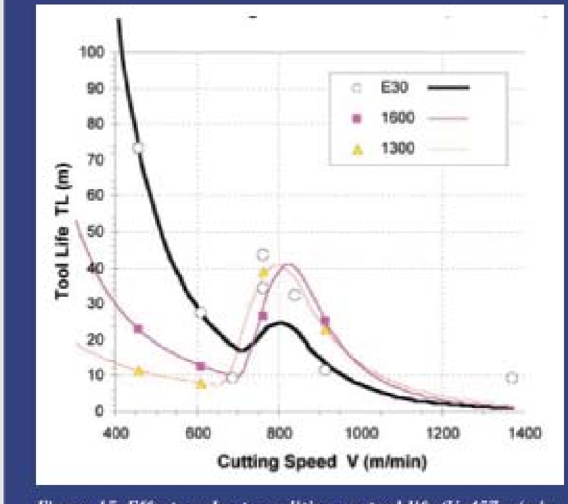

Figure 15: Effect coolant condition on tool life (V=457m/min, h_x=0.025mm, a_e=0.25mm)

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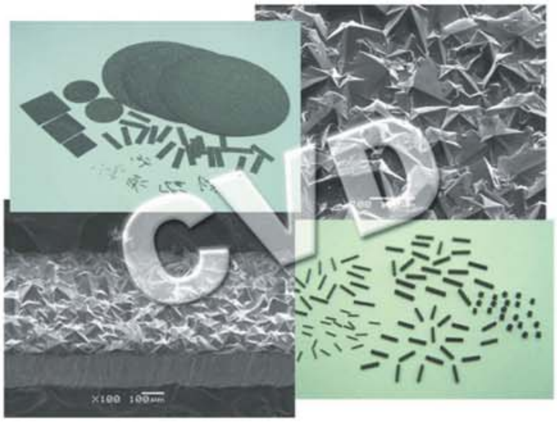

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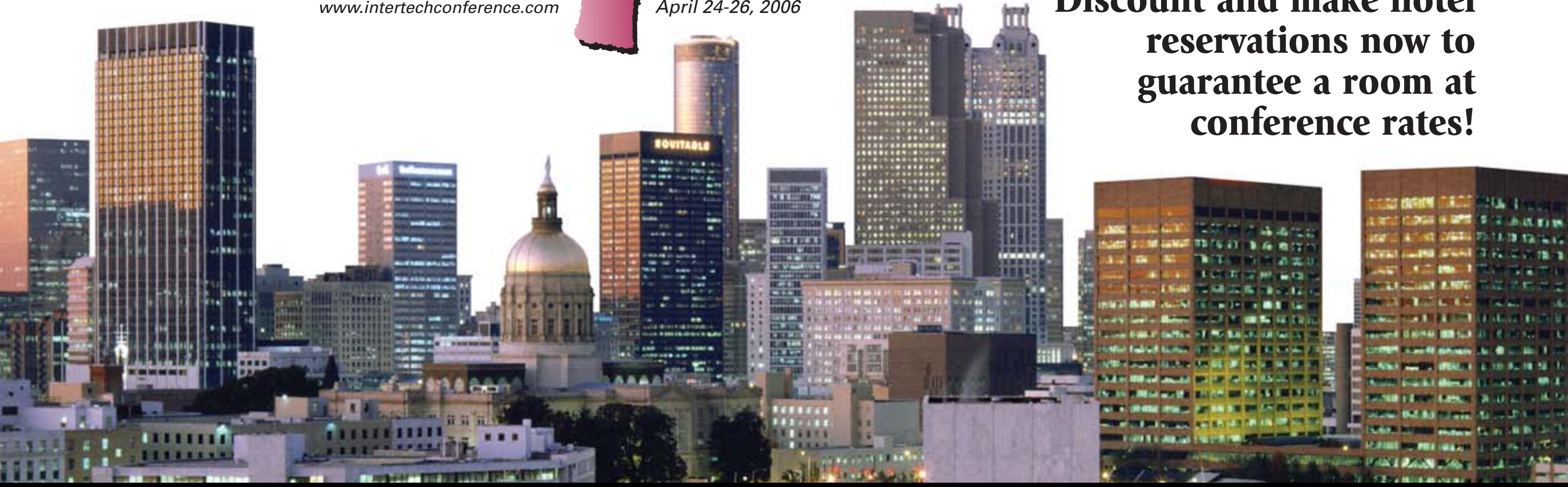

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Use a separate form for each conference registrant. ***PLEASE PRINT CLEARLY.***

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Contact Terry or Kathy Kane at the Industrial Diamond Association ... **614-797-2265** or E-mail: **tkane-ida@insight.rr.com**

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January 9-10
Cost and Schedule Estimation for Project Managers and Decision Makers
Los Angeles, CA
UCLA Department of Engineering
www.uclaextension.edu/shortcourses

SME Manufacturing for PERFORMANCE

January 23-25
Manufacturing for Performance
Indiana Convention Center
Indianapolis, Indiana
www.sme.org/motorsports

SME Society of Manufacturing Engineers

January 25-26
Nanomanufacturing Conference & Exhibits
Troy, MI
www.sme.org

January 28-February 1
The Concrete Sawing and Drilling Association Annual Convention
Charleston, South Carolina
727-577-5004 or visit www.csda.org

January 31
CSDA Tech Fair
Charleston Place Hotel
Charleston, SC
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February 16-17
Cutting Edge Training
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Clearwater, FL
727-577-5004 or visit www.csda.org

February 18
OSHA Construction Safety Training
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February 20-21
Estimating Training
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727-577-5004 or visit www.csda.org

February 22-24
Spray Finishing Technology Workshop
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March 23-26
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Renaissance Scottsdale Resort
Scottsdale, Arizona
www.uama.org

March 27-30
Metalworking Fluids Management Certificate Program
Los Angeles, CA
www.sme.org

March 27-30
Advanced Productivity Exposition WESTEC 2006,
Los Angeles, CA
www.sme.org

SME Society of Manufacturing Engineers

March 27-30
The SME Summit & Annual Meeting
Los Angeles, CA
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SME
March 28-29
Lean Certification Exam Preparation Course
Los Angeles, CA • www.sme.org

March 28-30
NanoManufacturing Conference & Exhibits
Los Angeles, CA • www.sme.org

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April 1-3
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April 4-6
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www.sme.org

April 19-20
Midwest Job Shop Show
Covington, KY
Job Shop Network Phone: 203-758-4882

April 22-23, 2006
Industrial Diamond Association of America
60th Anniversary and Annual Meeting
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Atlanta GA, USA
www.superabrasives.org

INTERTECH 2006
An International Technical Conference on Diamond, Cubic Boron Nitride and their applications.
www.intertechconference.com
THE GRAND HYATT ATLANTA IN BUCKHEAD
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www.itssexpos.com

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The 2006 Superabrasives Resource Directory is Coming Spring 2006

Don't miss this valuable opportunity to have your company listed.

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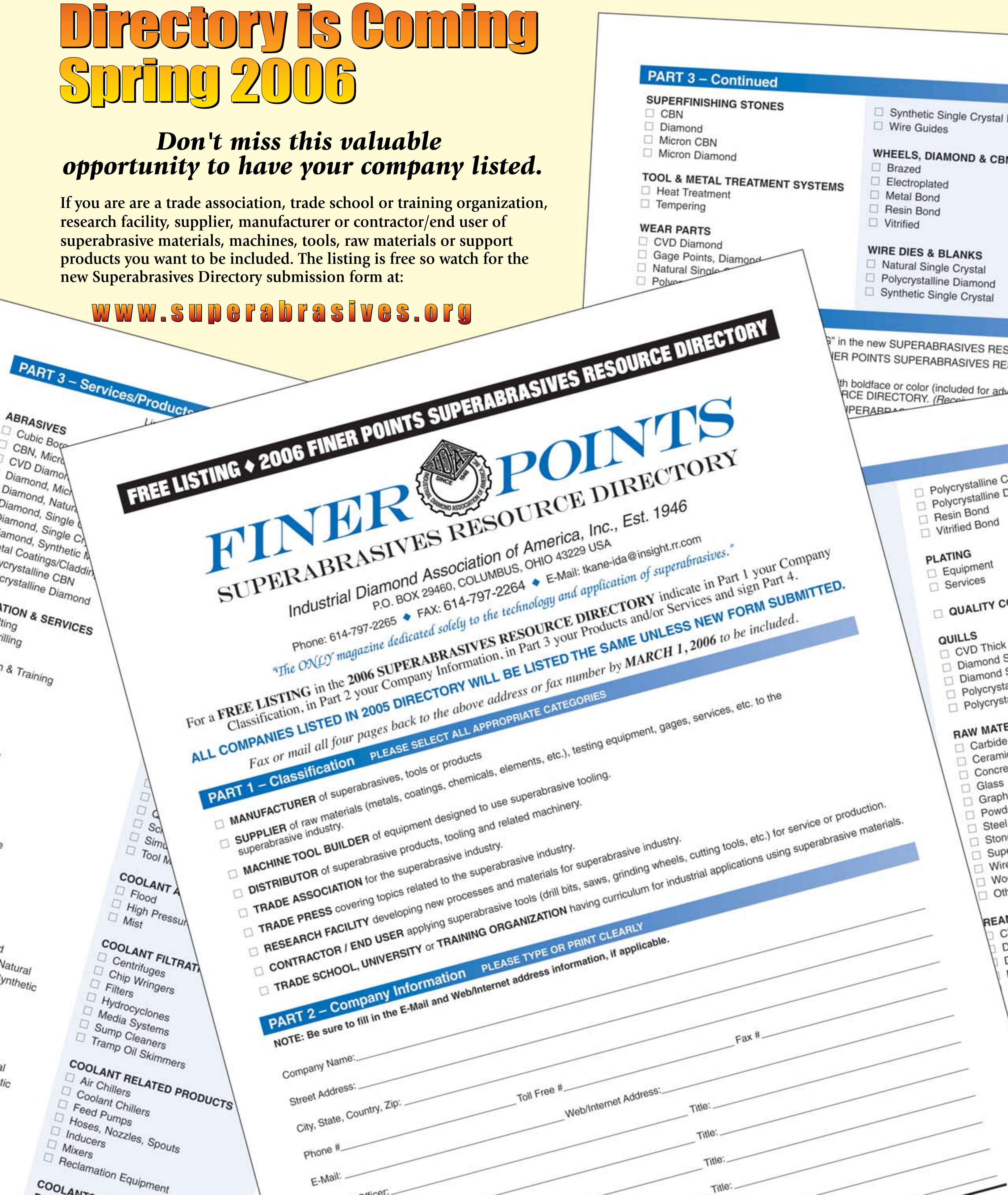
www.superabrasives.org



FREE LISTING ◆ 2006 FINER POINTS SUPERABRASIVES RESOURCE DIRECTORY

FINER POINTS

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For a **FREE LISTING** in the **2006 SUPERABRASIVES RESOURCE DIRECTORY** indicate in Part 1 your Company Classification, in Part 2 your Company Information, in Part 3 your Products and/or Services and sign Part 4.

ALL COMPANIES LISTED IN 2005 DIRECTORY WILL BE LISTED THE SAME UNLESS NEW FORM SUBMITTED.

Fax or mail all four pages back to the above address or fax number by ***MARCH 1, 2006*** *to be included.*

PART 1 – Classification PLEASE SELECT ALL APPROPRIATE CATEGORIES

- ☐ **MANUFACTURER** of superabrasives, tools or products
- ☐ **SUPPLIER** of raw materials (metals, coatings, chemicals, elements, etc.), testing equipment, gages, services, etc. to the superabrasive industry.
- ☐ **MACHINE TOOL BUILDER** of equipment designed to use superabrasive tooling.
- ☐ **DISTRIBUTOR** of superabrasive products, tooling and related machinery.
- ☐ **TRADE ASSOCIATION** for the superabrasive industry.
- ☐ **TRADE PRESS** covering topics related to the superabrasive industry.
- ☐ **RESEARCH FACILITY** developing new processes and materials for superabrasive industry.
- ☐ **CONTRACTOR / END USER** applying superabrasive tools (drill bits, saws, grinding wheels, cutting tools, etc.) for service or production.
- ☐ **TRADE SCHOOL, UNIVERSITY** or **TRAINING ORGANIZATION** having curriculum for industrial applications using superabrasive materials.

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PART 3 – Continued

SUPERFINISHING STONES
- ☐ CBN
- ☐ Diamond
- ☐ Micron CBN
- ☐ Micron Diamond

TOOL & METAL TREATMENT SYSTEMS
- ☐ Heat Treatment
- ☐ Tempering

WEAR PARTS
- ☐ CVD Diamond
- ☐ Gage Points, Diamond

- ☐ Synthetic Single Crystal
- ☐ Wire Guides

WHEELS, DIAMOND & CBN
- ☐ Brazed
- ☐ Electroplated
- ☐ Metal Bond
- ☐ Resin Bond
- ☐ Vitrified

WIRE DIES & BLANKS
- ☐ Natural Single Crystal
- ☐ Polycrystalline Diamond
- ☐ Synthetic Single Crystal

- ☐ Resin Bond
- ☐ Vitrified Bond

PLATING
- ☐ Equipment
- ☐ Services

PART 3 – Services/Products

ABRASIVES
- ☐ CVD Diamond
- ☐ Metal Coatings/Cladding
- ☐ Polycrystalline CBN
- ☐ Polycrystalline Diamond

COOLANT FILTRATION
- ☐ Centrifuges
- ☐ Chip Wringers
- ☐ Filters
- ☐ Hydrocyclones
- ☐ Media Systems
- ☐ Sump Cleaners
- ☐ Tramp Oil Skimmers

COOLANT RELATED PRODUCTS
- ☐ Air Chillers
- ☐ Coolant Chillers
- ☐ Feed Pumps
- ☐ Hoses, Nozzles, Spouts
- ☐ Inducers
- ☐ Mixers
- ☐ Reclamation Equipment

Guest Editorial

Editor's comment: Ben Silverman recently took a job outside of the Industrial Diamond & Manufacturing industries. Ben wanted to provide a short editorial on his time in the industry and his experiences, both as a Member of the Industrial Diamond Association (IDA) and furthermore on his term as a Director for the Association. We will miss Ben in this industry and wish him all the best in his new endeavor.

BEN SILVERMAN

Membership And Participation In The Industrial Diamond Association Is Time And Money Well-Spent With Tremendous Payback

By **Ben Silverman**, *Former Executive Vice President & General Manager, Greenlee Diamond Tool Company & DoALL Cutting Fluids*

You wouldnít sail across the Atlantic without a Global Positioning System (GPS) and you shouldn't run your business without the Industrial Diamond Association (IDA). If you are like most competent managers, you know your good customers and what they expect, you know which processes need to be corrected, you have an A-list of product development initiatives and you expect to improve your business in the coming year. I was in this position in 2001 before becoming active in the IDA. My business was on solid ground coming out of the economic slowdown. However, the IDA helped me lead my business much more clearly and effectively by providing a wider industry perspective and a sharper view of the industry horizon.

The IDA provides many key resources and you will make better business decisions if you take advantage of them. First, the annual meeting provides a great primer to prepare for the coming year. Your IDA assembles a very relevant slate of topics – economic forecasts, large end-user presentations, introductions to new technologies, industry specific government regulations and operating guidelines, and presentations on global trends in our industry. The quality of the material will be excellent and ***you will learn even more from the questions and comments of other IDA members during their discussions and interaction***.

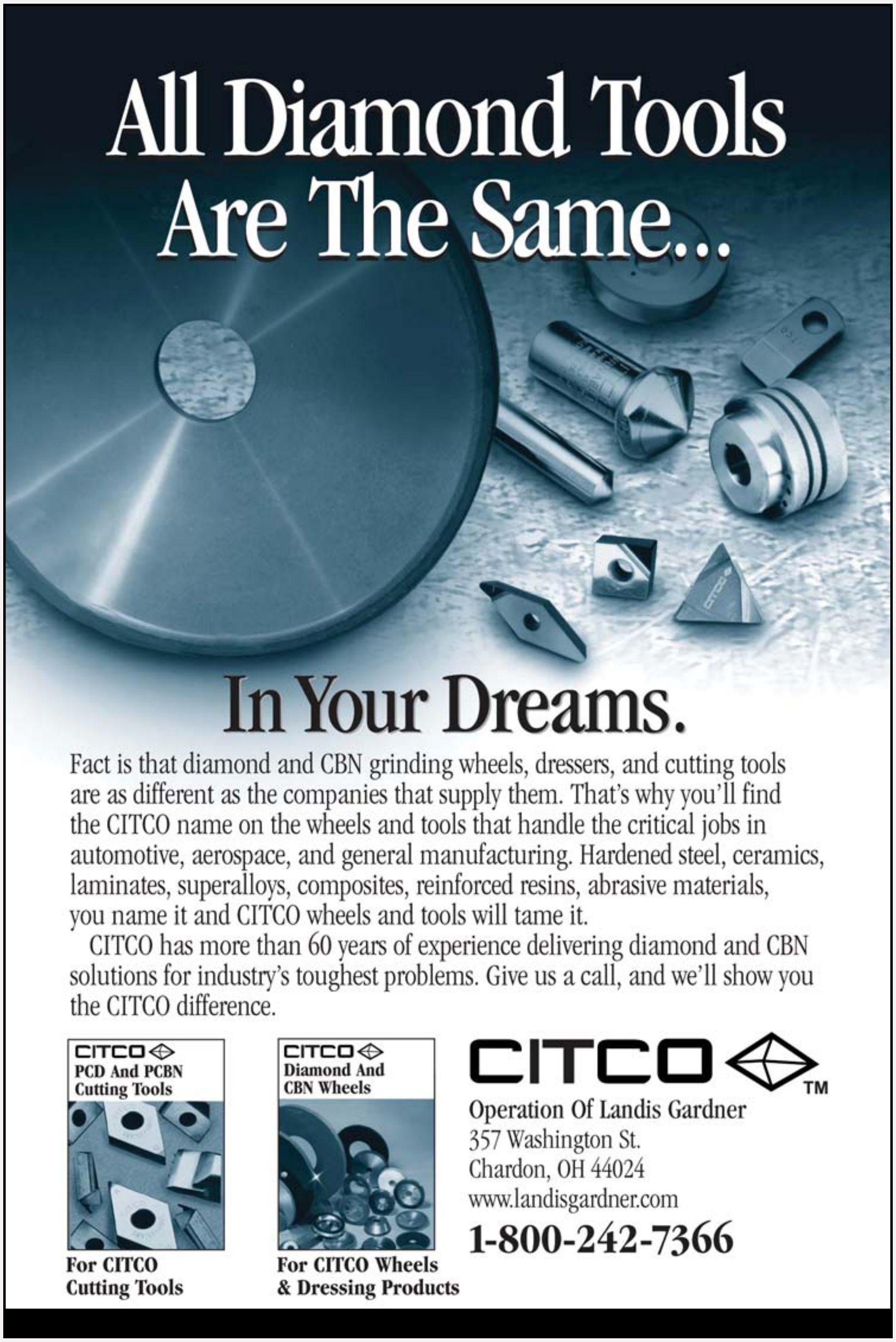
Second, with so much happening on a global scale in our industry, you need to broaden your network to stay in the loop. IDA representatives from member companies are the most knowledgeable and useful resources you have to gage what is happening in our industry. We all compete in the same economy. Sometimes you grow by finding new markets and sometimes you grow by beating your competition. Industry networking will help you do both much more efficiently.

Lastly, the IDA anchors our industry's key events. It is active in promoting technical education on industrial diamond processes and works with other associations to promote and grow our industry. Most importantly, the IDA plans and runs INTERTECH, the best technical conference in our industry. You can attend INTERTECH without helping to plan it, but you will learn so much more by being involved in making it happen.

If you are like I was, you feel too busy and committed to your company to ìhelpî your industry and ìsupportî an association of your suppliers and competitors. How wrong I was!!! The time I spent actively participating in the IDA, since 2002, has paid me back many-fold. It gave me a better map of the state of our industry and a realistic view of where my company was positioned and where we needed to go. Membership and participation in the Industrial Diamond Association is time and money well-spent with tremendous payback.

ABOUT THE AUTHOR:

BEN SILVERMAN is the Former EVP & General Manager of Greenlee Diamond Tool Company & DoALL Cutting Fluids. Mr. Silverman joined DoALL in 1997 and prior to DoALL, he spent 8 years in abrasives and automotive components manufacturing, including 3 years with GE Superabrasives and 5 years with GE. Mr. Silverman has a Bachelorís and Master's of Mechanical Engineering from MIT and an MBA from the University of Chicago. Ben recently joined Rain Bird Corporation as Director of the Consumer Products Business Unit. He currently resides in Tucson, AZ and can be contacted at bsilverman@rainbird.com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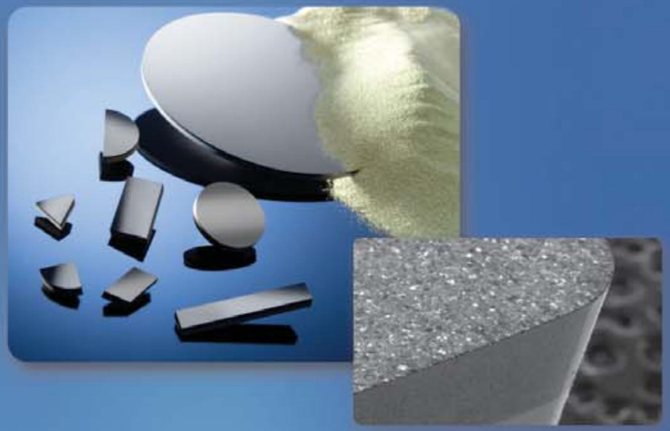
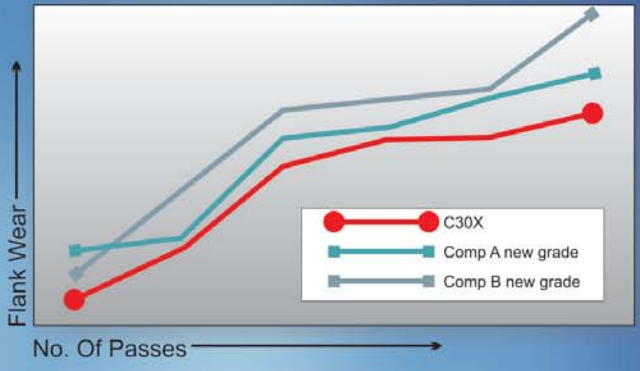


Tool Wear



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Abrasive Wear Behaviour of Diamond Composite Cutting Elements

DR. JAMES N. BOLAND, Research Group Leader
CSIRO Exploration and Mining • Kenmore, Australia

Off shore drilling and other exploratory mining elements provide severe wear conditions for diamond drilling cutters. A new wear testing rig has been designed and built to assess the abrasive wear behaviour of superhard materials such as diamond composites. The purpose of the testing procedure is to subject the cutting element of the tool to a "near service" condition, involving both cutting and abrasive processes. Both standard grinding wheels and non-standard rock wheels can be used to determine the suitability of such cutting elements to the harsh conditions encountered in the cutting of hard and abrasive rocks with high rock mass ratings (RMR values). In our testing program we have been able to determine the quality of materials produced by a range of manufacturers and to select those products that are suitable for insertion into rock cutting tools such as pointattack picks, drill bits and saw blades. The results of our wear studies of superhard diamond composite materials are presented.

Determining The Behaviour Of Diamond Composite (DC) Materials

Exploiting the unique physical properties of diamonds in tooling for mineral excavation, rock cutting and rock drilling is not new. While hand-set diamond drill bits with carat sized natural diamonds were manufactured in the 1920s, it is more usual to have the diamonds either surface-set in the bit or incorporated into a suitable matrix material as in impregnated diamond bits. One further development in diamond tooling that has made a major impact on the economics of exploration and mining is the discovery of polycrystalline diamond composite materials. These materials are variously referred to as polycrystalline diamond (PCD) as in Photo 1, polycrystalline diamond compact (PDC) and thermally stable polycrystalline diamond (TSP, TSD or TSDC) depending on the chemical composition and physical format of the manufactured component.

The behaviour of any of these diamond composite (DC) materials is dependent on the type of binder used, assuming in the first instance a comparable quality of diamond grit is used to manufacture the composite itself. In general, DC material with Co binder is limited in its range of operation because of the rapid increase in wear rate when the temperature on the tool exceeds 700°C. A major breakthrough was achieved with a change in the binder phase to material that did not catalyze the back phase transition of diamond to graphite as has been observed with DC-Co. There are several possible materials that satisfy this requirement but silicon is most commonly used. However, the success of these composites depends on a more complex process involving the infusion of Si as a melt phase and a reaction-bonding process in which the Si reacts with the diamond to produce SiC. There are three known manufacturing methods used to produce thermally stable DC material via a silicon, reaction bonding process: (a) a high pressure-high temperature process within the diamond stability field, (b) high pressure-high temperature process but within the graphite stability field and (c) a high temperature sintering process, either under axial loading or under vacuum conditions such as ScD Skeleton cemented Diamond (photo 2). Such TSDC materials can be operated at temperatures in excess of 1200°C.

There are several manufacturers of TSDC materials claiming to produce reliable cutting element. However, it is essential to be able to perform simple, rapid and low-cost quality checks on such materials to ensure that they will perform reliably when they are inserted into cutting tools. To this end, a simple but direct testing procedure was devised, based on a wear testing rig designed and built to measure the relative abrasive wear characteristics of a range of TSDC materials under cutting as well as abrasive wear conditions. This article describes this wear rig and presents the results of a series of tests on range of TSDC materials.

Photo 1 Polycrystalline Diamond Blanks

NEWS and notes

IN MEMORIAM

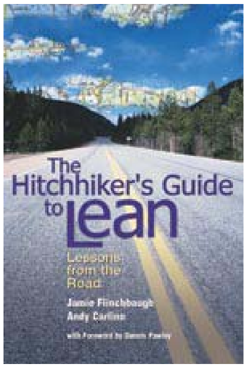
We in the Industrial Diamond industry recently learned of the sudden passing of VINCENT LISANTI, President of Industrial Diamond Laboratories, Inc. Anyone who ever met Vince, respected and admired him. He was a good friend to all who knew him and he had many from being in the diamond business for close to 45 years. Vince worked his way up in the industry, until he eventually started his own business. His wife and best friend of 42 years, Gloria, and his two sons Anthony and Vincent survive him. Anthony has been in the diamond business working alongside his father, and is now running the day-to-day operations of the business. Vincent also has two daughter-in-laws and five grandchildren that meant the world to him. His family and his many friends in the diamond industry will miss him.

ABB JAPAN ORDERS ADDITIONAL BRAINTECH SOFTWARE EVISIONFACTORY FOR JAPANESE AUTOMAKER

Application Will Use ABB's TrueView Seam-Sealing System

Vancouver, British Columbia, 2005 – Braintech Inc., a leading provider of vision guided robotic software and solutions, announced today that it has received two additional orders for eVisionFactory™ (eVF™) solutions from strategic partner ABB, for a Japanese automaker. eVF is the key ingredient in ABB's TrueView™ vision guidance application for seam sealing. They will be added to the same production line to further automate the sealing process and will complete the seam sealing automation on the vehicle body. For more information, visit www.braintech.com

SME RELEASES NEW BOOK THE HITCHHIKER'S GUIDE TO LEAN


The Hitchhiker's Guide to Lean
Lessons from the Road
Jamie Flinchbaugh
Andy Carlino
with Foreword by Dennis Pawley

Dearborn, Michigan, December 13, 2005 – The Society of Manufacturing Engineers (SME) today announced the release of "The Hitchhiker's Guide to Lean: Lessons from the Road" www.hitchhikersguidetolean.com, a book that shares lessons learned from real applications and results of applying lean. "This book will help you learn lean, taking you through everything from lean principles to pitfalls to avoid. Creating change, particularly the kind discussed in this book, is a war. It is a war to win the minds and hearts of people and lead them where you want to go," said Dennis Pawley, contributor to "The Hitchhiker's Guide to Lean."

The book's 10 chapters cover lean principles and thinking, lean leadership moves, the roadmap for lean transformation, common pitfalls of lean journeys, building an operating system, lean accounting, lean material management, lean in service organizations, and how individuals can apply lean to improve themselves. Order online at: www.sme.org/store

CARLISLE ACQUIRES OFF-HIGHWAY BRAKE BUSINESS OF ARVINMERITOR

Bloomington, 2005 – Carlisle Motion Control Industries, a subsidiary of Carlisle Companies, strengthened its leadership position in the off-highway braking market with the acquisition of the assets of ArvinMeritor, Inc.'s off-highway business. Carlisle Industrial Brake and Friction manufactures brake systems for heavy duty mining, construction, industrial, and agricultural equipment. The company produces friction products for such varied applications as on- and off-highway vehicles, industrial equipment, lawn and garden equipment, and consumer appliances. For further product information contact: www.carlislebrake.com

Friction Products

There are several manufacturers of TSDC materials claiming to produce reliable cutting element.

Photo 2 - Skeleton cemented Diamond (ScD) is a superhard, tough and extremely wear resistant diamond composite, manufactured by powder metallurgical methods.

Photo 3 - Wear test on corundum

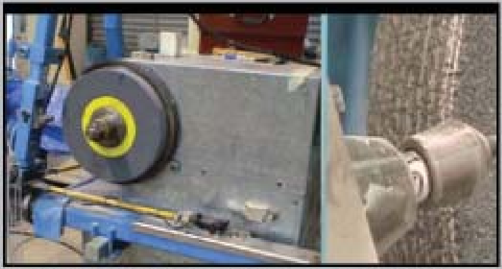


Photo 4 Wear test rig: (left) general view of wheel, sample holder on loading jig, loading arm with load cell attached. (right) detail of sample in holder prior to engaging the wheel.

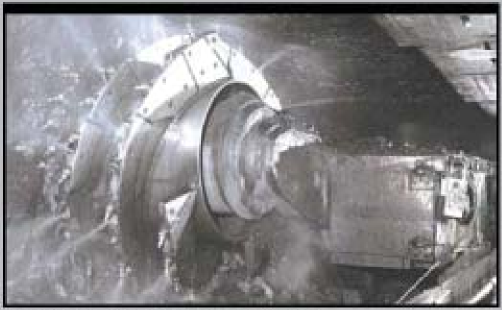


Photo 5 - rock cutting machine

Table 1: Properties of the grinding wheel

PROPERTY	
Density, g/cc	2.18±0.01
UCS, MPa	120.67±1.53
Tensile Strength (Brazilian), MPa	19.76±1.47
CAI (Cerchar Abrasivity Index)	3.54±0.55
Porosity (volume %)	~42
Al2O3 grain size, μm	~400

(Code: 1146550; size: 1A 350x50x50.8;spec.:A 60 M V; max speed: 1800 RPM/33m/s)

Wear Test Rig

The essential features of the wear test rig are:

- Grinding wheel;
- Sample holder;
- Force gauges;
- Cutting action for DC element.

While there is a range of grinding wheel material to choose from, a corundum wheel of standard manufacture was chosen in preference to a SiC based wheel (photo 3). A general view of the rig is shown in Photo 4. The general properties of the alumina grinding wheel are given in Table 1.

The sample holder consists of a collet arrangement that can be made to accommodate a range of DC elements. An essential feature of this design is to ensure there is good mechanical and thermal contact between the element itself and the holder. The attack angle of the cutting element can be adjusted to simulate the cutting geometry of the tool when installed on the rock cutting machine (photo 5).

The speed of the wheel can be controlled to maintain a constant, effective linear speed of cutting during the tests. To create maximum abrasivity, all cutting trials reported in this study have been performed dry. However, to ensure a favourable heat sink under the dry cutting operation, the back of the tool holder may be water cooled. All fine dust generated during the shallow cuts was collected by an industrial dust extraction system mounted adjacent to the cutting interface. The next important feature of the rig is to simulate both cutting and abrasive wear conditions likely to be experienced by the cutting element under practical operations in the field. This is achieved by zeroing the DC element at the beginning of the test and then setting the cutting head to a predetermined depth-of-cut. The wear test is initiated and the element is forced to cut into the wheel at the

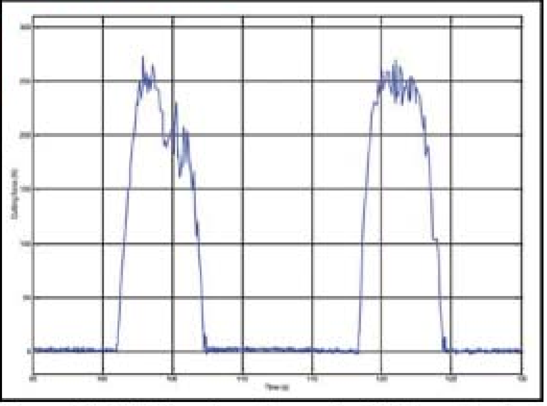


Figure 2 (a) Cutting force traces for 0.25 mm depth-of-cut in corundum (Al2O3).

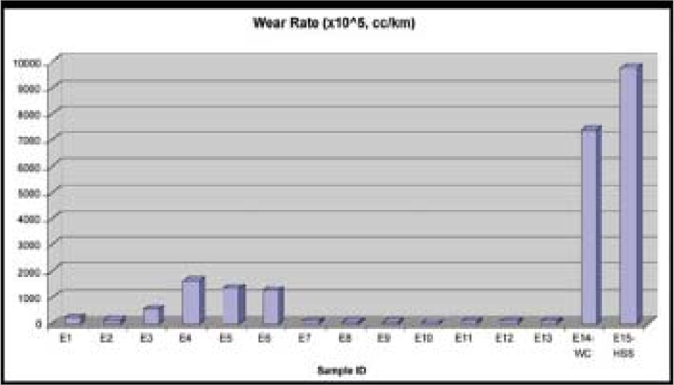
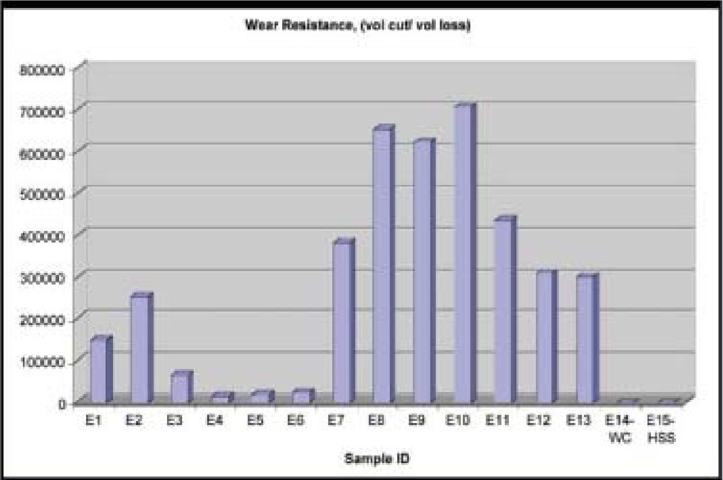


Figure 1 Wear parameters used to assess the quality of TSDC cutting materials. Top: wear rate represented by volume loss of TSDC per kilometer of cut; bottom: wear resistance given by the ratio of volume of wheel cut per unit volume of worn TSDC.



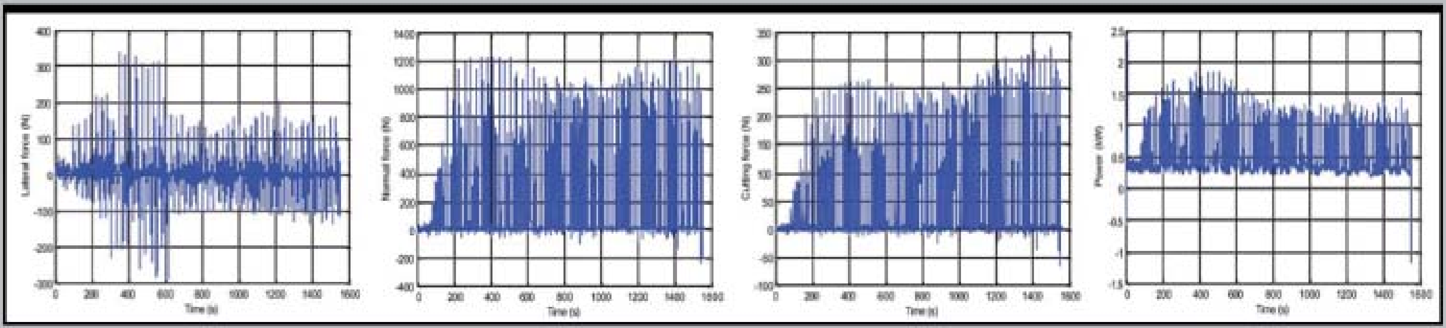
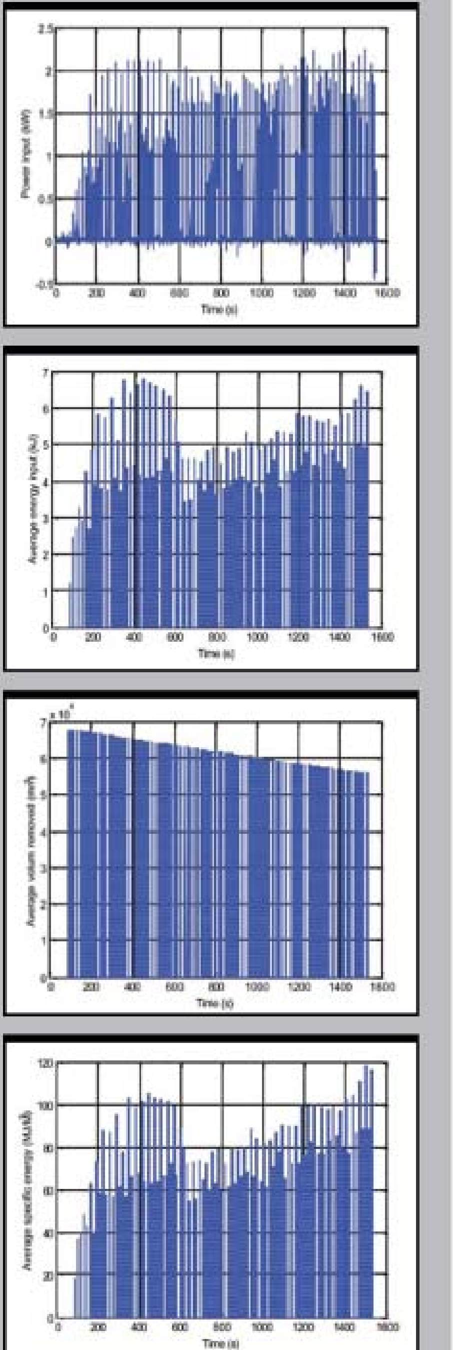
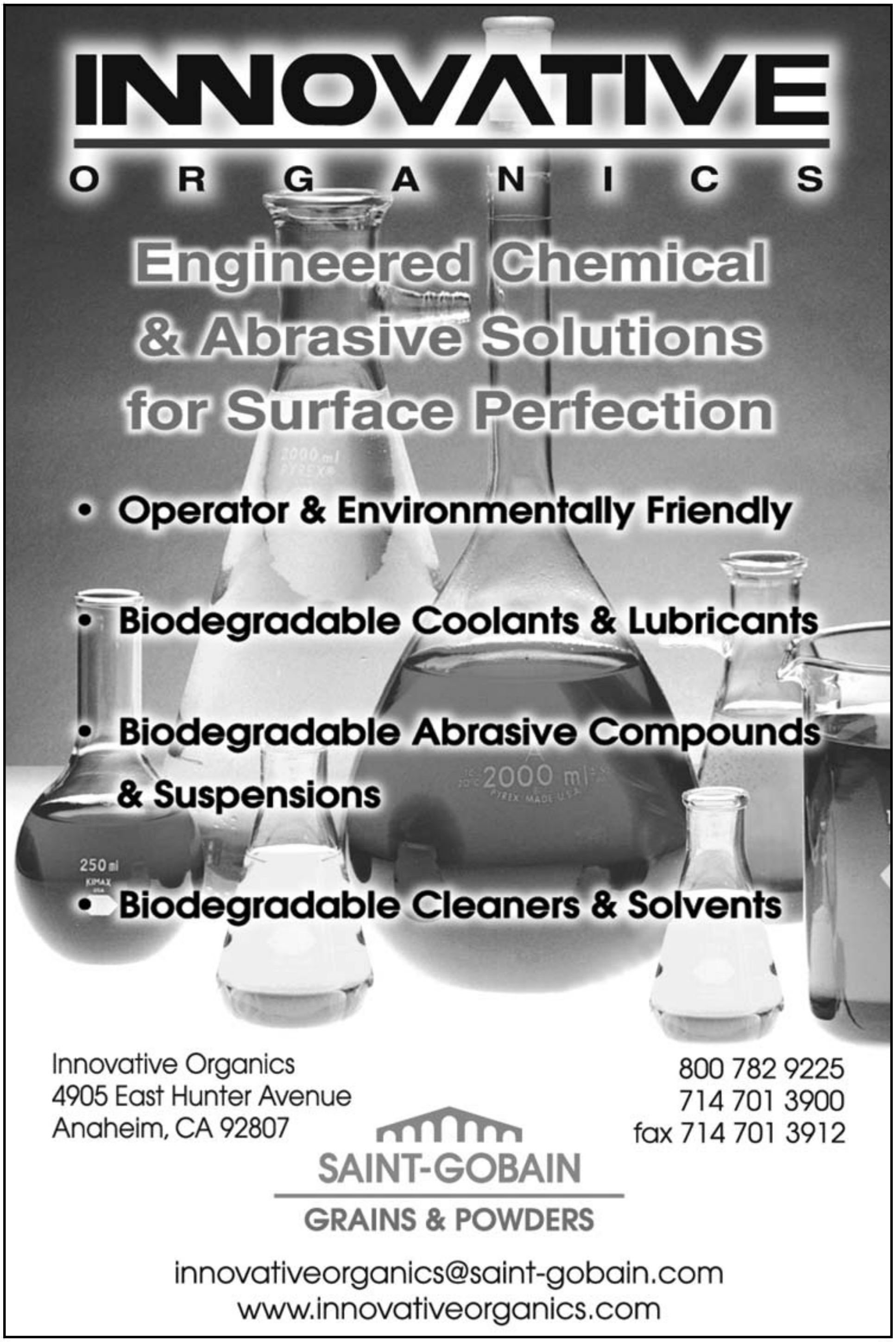


Figure 2 (b) A set of parameters derived from a cutting trial involving 95 cuts across the wheel. Parameter: (a) forces - lateral, normal and cutting; (b) Electrical power;(c) Power and energy as measured at the cutting element; (d) volume of wheel removed and (e) Specific energy (SE) of the cutting operation.

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preset depth, executing a series of cuts. The actual number of cuts depends on the wear resistance of the element. For highly wear resistant materials, it is usual to perform 100 cuts but this had to be carefully monitored for the softer carbides used in the cutting trials.

With load cells mounted in the connecting push rods (note connecting rod under the grinding wheel in photo 1), the forces on the DC element are monitored throughout the cutting trials. These forces are resolved into the feed (or lateral), thrust (or normal) and principal (or cutting) forces using the nomenclature from cutting operations. From the cutting force, the specific energy (SE) may be calculated knowing the volume of material removed during the trial. The wear behaviour of the DC elements is assessed in terms of the weight or volume loss of the cutting element and the volume of material removed from the grinding wheel.

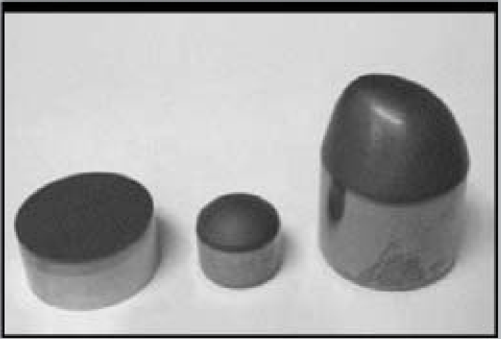


Photo 6 - DC cutting elements

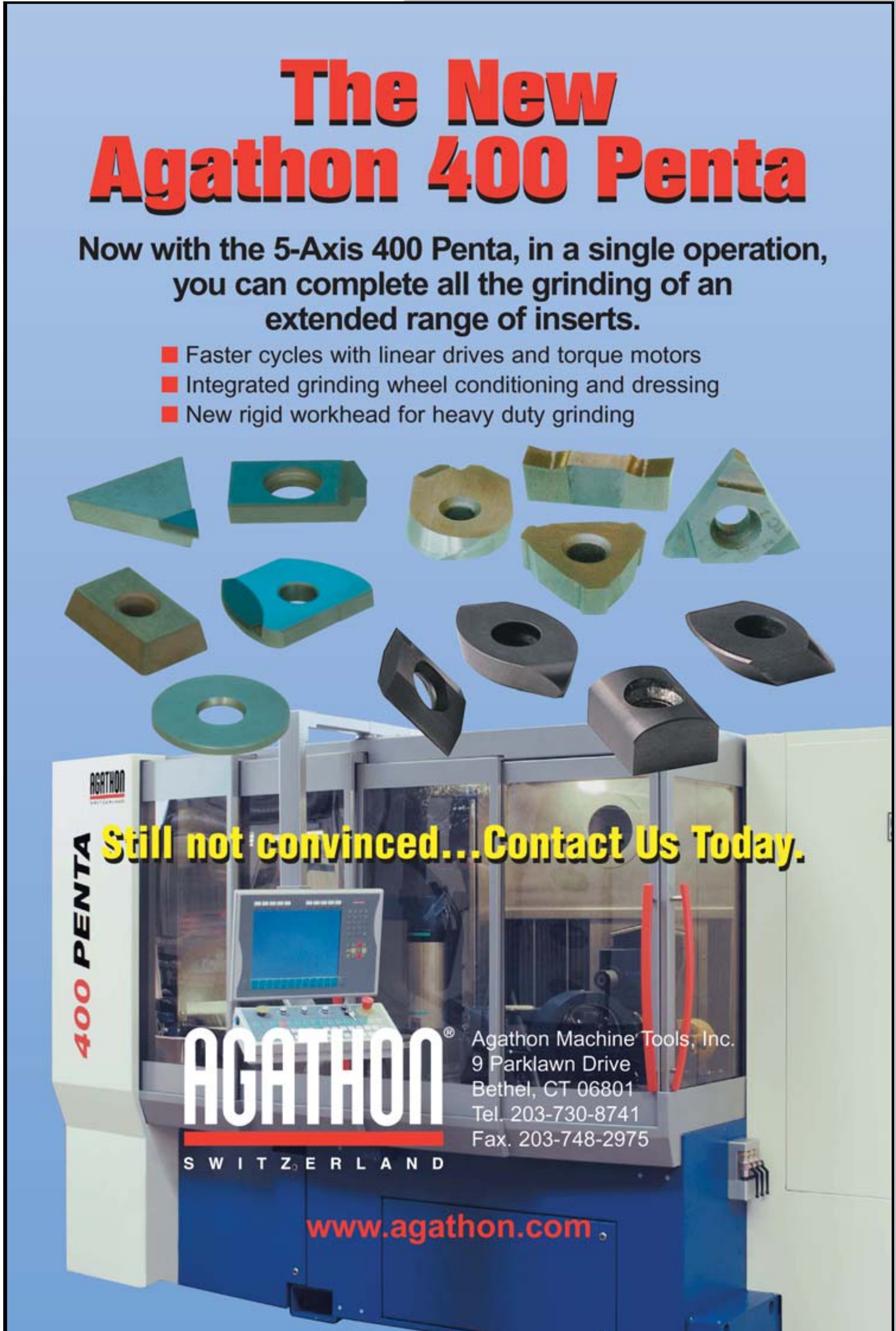
Abrasive Wear of Diamond Composite Materials

Wear tests were performed on several types of DC material and the results presented in figure 1. The series E1 to E13 were TSDC materials from several manufacturers, E14 was a standard, rock-cutting grade of cemented tungsten carbide (WC) and E15 was a high speed steel.

Various parameters may be used to represent the wear behaviour of materials but the two shown in figure 1 are the wear rate in units of volume loss of cutting element (units: cc) per kilometer of cutting and wear resistance given as volume of wheel cut per unit volume of material loss of the cutting element. The latter can be consider as a cutting ratio, similar to a grinding ratio G, except it is the inverse of G. All the wear testing was performed without coolant with an equivalent linear speed of the wheel ranging from 6.5 to 8 m/s.

Another useful set of parameters that can be derived from the wear rig are the forces, specific energy (SE) and power. Examples of these parameters are shown in figure 2.

The initial purpose of the wear rig was to assess the relative wear resistance of specially designed DC cutting elements as supplied by several manufacturers. Hence the shapes of these elements were comparable. These shapes, however, were not suitable for measuring the more fundamental dimensionless wear coefficient, K, that appears in the Archard wear equation. Because of the conic profile of the cutting element (photo 6), the wear surface area increases with cutting distance so one might expect the average cutting and normal forces to



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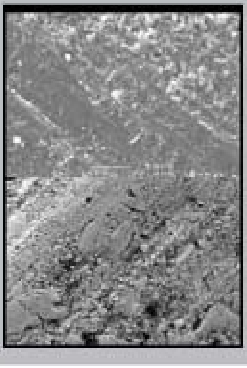

Photo 7 - SEM images of worn surfaces. (left) Alumina coating over surface of TSDC cutting element after 100 cuts; (right) WC-Co surface after 10 cuts.

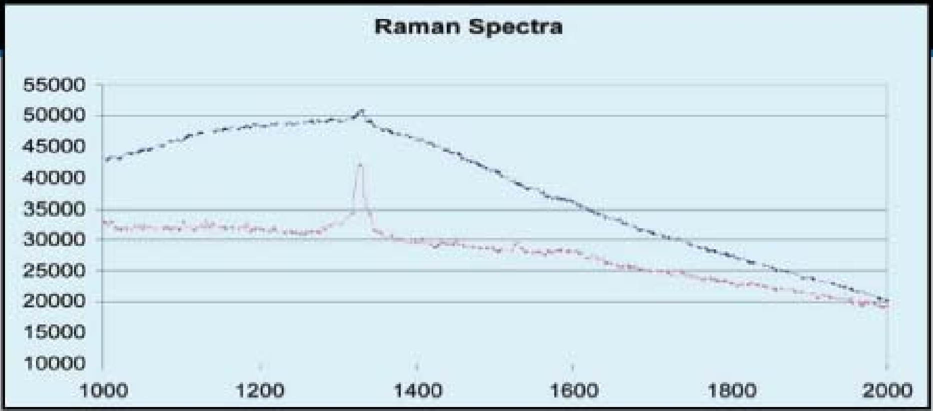

Figure 3 - Raman spectrographs of unused (top) and worn (bottom) TSDC cutting elements.

increase - this is observed in most of the cutting trials.

While some microstructural studies of the worn surface of the DC elements have been made using scanning electron microscopy (photo 7), the results of Raman spectroscopy on the worn surface indicated that there was no significant graphitization of the diamond, despite the high temperatures known to be generated on the cutting interface – figure 3.

Wear Testing Rig Is Capable Of Producing More Quantitative Information

While, to a first approximation, most DC materials are strong and wear resistant, it is important to have access to a simple quality assessment device to check the relative merits of material from a variety of sources. The wear test rig described in this article was designed and built for this purpose. It is known that some manufacturers use a simple density measurement to assess the quality of DC but that test alone has been shown to be inadequate to decipher the quality of product. By having access to a simple wear test rig, it is possible to test selected samples from the different batches of DC material to ensure quality of supply of such ultrahard materials. The wear testing rig is capable of producing more quantitative information on the wear behaviour of DC materials. In addition to the forces and electrical power consumption, it is possible to derive more fundamental information such as wear coefficients and interfacial temperatures. However, these initial tests have more than proved the worth of the rig for both establishing a relative wear resistance assessment of DC materials and cross checking the quality of different batches for the same DC supplier. ■

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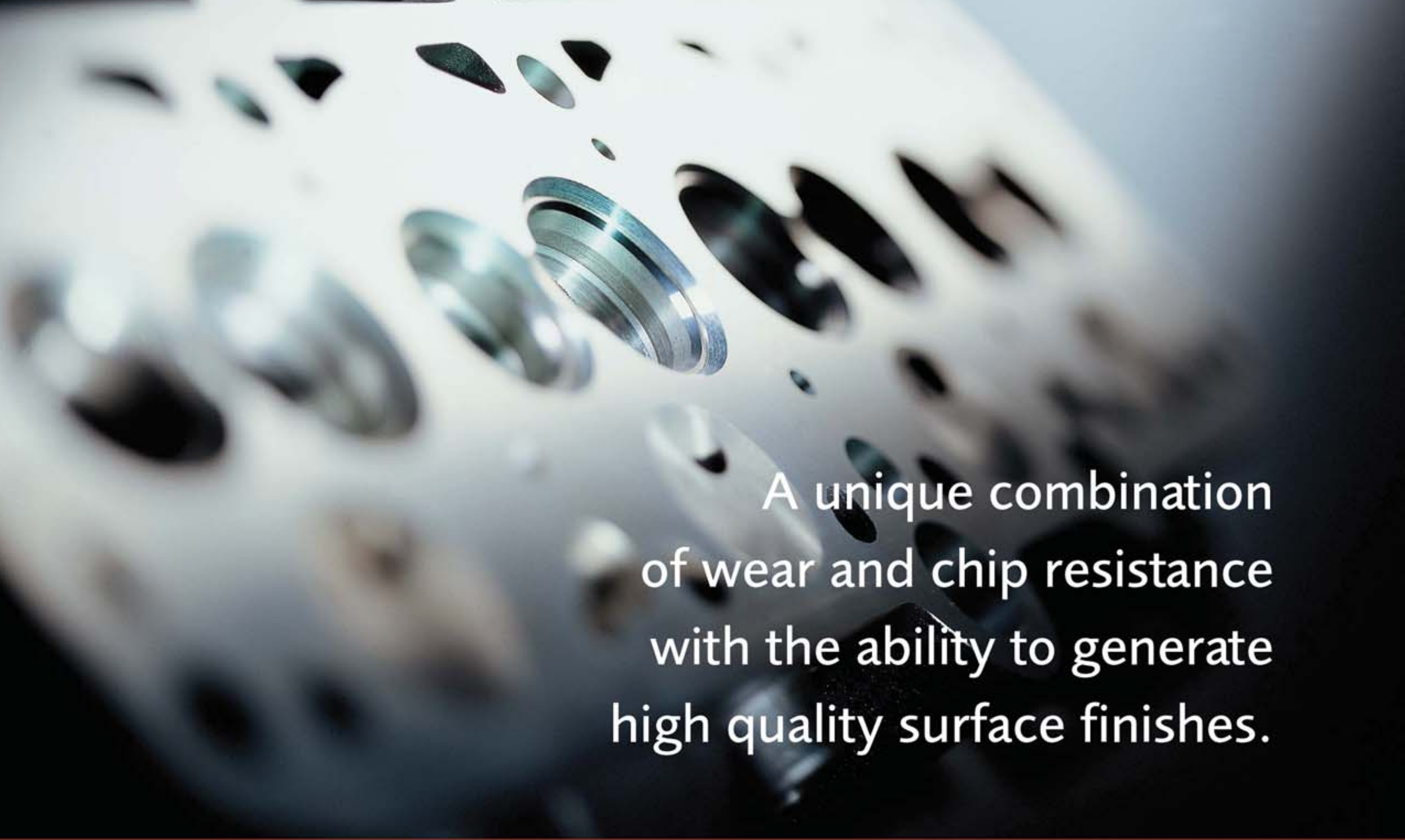
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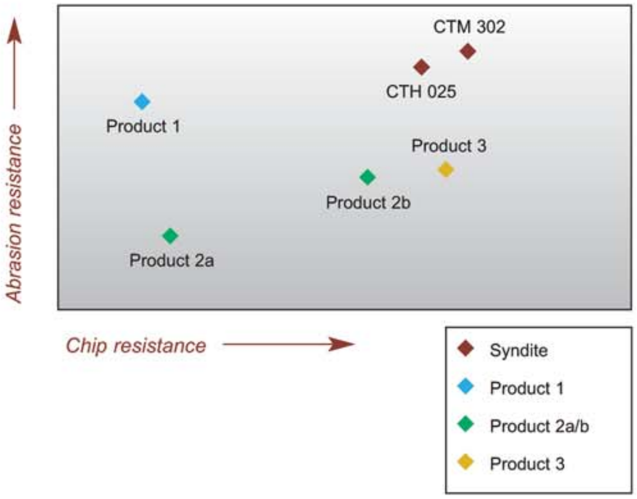

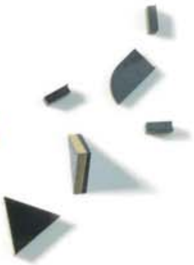

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